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CONTENTS

About This Issue 198

Management Policy of the Philips Research Laboratory
HENRI BIENFAIT 201

Creativity in Research Organizations
IRVING REICH 217

Proceedings of Industrial Research Study Group Meetings. Number 2. Job Status as an Award for Scientific and Administrative Accomplishment
JAMES A. BRALLEY 227

Job Status for the Research Scientist
FRANK H. HEALEY 239

Improving the Technical Competence of Research Workers
LAWRENCE H. DUNLAP 245

Theory of Communications in a Research Laboratory
JAMES HILLIER 255

Book Review: Handbook of Industrial Research Management, Carl Heyel, ed. Reviewed by
LAUREN B. HITCHCOCK 271

Index 275

Volume Title Page i

Volume Contents iii

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ABOUT THIS ISSUE

The Spring 1960 meeting of the Institute had a session devoted to Administration of Overseas Research. Our first article reports the presentation made by a distinguished representative of a world-renowned scientific organization. Dr. Henri Bienfait is Deputy Director of the Philips Research Laboratories at Eindhoven, Netherlands. He discusses the company's philosophy and management policies which are remarkable not only for their technical qualities but also for their deference to the psychological and social forces that make for progress. That the company's management has been successful is attested by an impressive list of accomplishments over the whole R & D spectrum of fundamental research, application, development, manufacture, and sales. From modest beginnings the Philips organization has become a great international enterprise firmly based upon science and technology. Dr. Bienfait's paper is entitled "Management Policy of the Philips Research Laboratory."

So much has been written on creativity that the need for an additional article on the subject might well be questioned. At the start of our reading we did indeed consider Dr. Reich's paper with an attitude of skepticism, but at the conclusion we decided that here is not just a rehash of an old theme, but instead a distinctly original and valuable contribution. "Creativity in Research Organizations" is a penetrating analysis of the factors involved, written with candor, insight, and skill by a man who himself has earned a reputation for ability and productiveness at the bench. Dr. Irving Reich is presently Director of Proprietary Research for Carter Products Company, New Brunswick, N. J.

The second report of proceedings of the IRI study group conferences deals with the subject of job status as an award for scientific and administrative accomplishment. The topic was subdivided into three parts: position analysis, the scientific ladder, and recognition and awards. Dr. Bralley prepared this report from detailed notes which he made while in attendance at the two conferences which were held on that topic. He records the salient observations made by the participants and the conclusions which were reached. Dr. James A. Bralley, who also prepared the report on creativity which appeared in the two preceding issues of *Research Management,* is Director of Chemical Research of A. E. Staley Manufacturing Company. His services were loaned to the Institute by that organization.

When the concept of the scientific ladder began to win recognition, the administrative or managerial ladder was already a time-honored and accepted means of advancement. Since both exist for the technical people of an organization it seemed but natural to compare the rungs level for level. Such comparison is not realistic, however, because of intrinsic differences in function and other reasons. The article entitled "Job Status for the Research Scientist" demonstrates quite effectively the nonparallelism of the two ladders. The author, Dr. Frank H. Healey, is Development Manager (Processing) in the Research and Development Division of Lever Brothers Company. He was a participant at one of the conferences of which the proceedings are reported in this issue.

The qualities involved in technical competence are not difficult to recognize; they generally fall into the categories of operational skills, technical knowledge, and the application of both to the resolution of specific projects. The measurement of these qualities does present problems which, however, are far from insoluble. Qualities recognized and standards of measurement applied, the next step is the setting-up of a method for improvement in technical competence, and this is followed by implementation. The entire program is indeed feasible provided it has

the support of a management with technical insight and a warm feeling for the sensibilities of the individuals concerned. Results of the program can be measured in company profits, job satisfaction, and high morale. The article entitled "Improving the Technical Competence of Research Workers" presents an able discussion of this vital aspect of research management. The author, Dr. Lawrence H. Dunlap, is General Manager, Chemistry Division, Research and Development Center of the Armstrong Cork Company.

The art of management involves continual examination of the factors which influence the success of a research program, in order to isolate all the elements which can be recognized, thus reducing the uncertainties to a very minimum. Of particular importance is the study of communication, which reveals that the capacity of human beings for reception and transmittal of information is exceedingly minute as compared with the total information available. Careful selection is therefore needed to increase the odds that the scientists will be exposed to the information he needs when he needs it. The article entitled "A Theory of Communications in Research Laboratory" not only demonstrates the vast complexities inherent in the problem of optimum communication, it also provides guide lines to the areas in which effort had best be devoted. The author, James Hillier, is Vice President of RCA Laboratories, Princeton, N. J.

This issue contains a review of the recently published *Handbook of Industrial Research Management.* The reviewer is Lauren B. Hitchcock of Lauren B. Hitchcock Associates. We intend to present reviews of new literature pertinent to the field of research management, and in that connection, the Board of Editors would appreciate the comments and suggestions of our readers.

MANAGEMENT POLICY OF THE PHILIPS RESEARCH LABORATORY*

HENRI BIENFAIT

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Research directors are interested in the future, little in the present, and less in the past. I must apologize, therefore, for beginning with some words on the past. I do this because it will give you an idea of the tradition and policy of our laboratory which may illuminate the present and by extrapolation make possible some remarks on the future.

History

The foundation of our laboratory was laid in 1914, when Dr. G. Philips, founder of the company, appointed Dr. G. Holst as the first physicist. Holst was then a 27-year old physicist, yet he had already acquired considerable experience. He had studied at Zurich and afterwards went to Leyden, where he worked as assistant to Kamerlingh Onnes on the compressibility of gases. There he had also assisted Mme. Curie in some of her measurements, and he was directly involved in the discovery of superconductivity—perhaps the most striking achievement of the Leyden laboratories. The Philips company at that time made only one product: incandescent lamps. After Holst had worked on various problems of photometric measurements, he was confronted with

* Paper presented in somewhat abbreviated form at the Spring Meeting of the Industrial Research Institute, Virginia Beach, Va., May 8–11, 1960.

the problem of short circuits destroying a certain percentage of the gas-filled lamps. The short circuit was caused by a gas discharge between the filament supports. This problem was solved by determining the optimal composition of the gas mixture that avoided this short circuit with minimal loss of efficiency. Once this difficulty was eliminated he could have left the problem altogether. However, Holst's curiosity was aroused. Could discharges in the noble gases be used as a practical source of light? Moreover, he was fascinated by these phenomena as such, especially because the theory of Bohr, which had just become known, made possible an insight into the mechanism of gas discharges. Through research on argon-filled lamps and rectifiers, on low voltage arcs, and the striated discharges in neon conducted with Dr. E. Oosterhuis and others, an insight into the various phenomena was gained which formed the fundamental background for a fruitful development of the gas discharge lamp. The latter had greater efficiency than customary lamps based on incandescent metals.

Recently I asked Holst what led him to take up gas discharge research. He answered the fun of finding out what happened in the arc and the possibility of applying the knowledge in some way.

Gas discharge phenomena were thus one of the main items of fundamental research in the laboratory during the years 1914–1933. Commercially the result was that we were one of the first companies to offer sodium gas-discharge lamps, the well-known road lighting, and the first to put high pressure mercury lamps on the market.

I mention this story in full because it seems to typify the start of more fundamental research and its commercial evaluations in an industrial laboratory.

I mention it also because in the thirties another domain of research was hit upon in quite a similar way. Like the theory of Bohr in 1913 for the gas discharge, wave mechanics in the late twenties permitted better understanding of the solid state. Could this be of any use to an electrotechnical industry, in which so many

solid materials were used in resistances, capacitors, and cores? Holst, intrigued by this question, persuaded some of his collaborators working on gas discharges to switch over to solid state research. Another question was raised: could not magnetite or some similar compound be improved and developed into a non-conducting ferromagnetic material? During the war research in this field led Dr. J. L. Snoek in our laboratory, carefully hidden from our uninvited guests, to the development of ferrites and other ceramic magnetic materials now extensively used in radio, television, radar, computers, etc. For a second time Holst, by taking on solid state research, had pressed the right button at the right time.

After the war even more nourishing fruits could be picked from the garden of the solid state. The transistor, a twin mutation of the rectifier, discovered and imaginatively cultivated at the Bell Telephone Laboratories, is an outstanding example. We may confidently expect that more exotic and useful plants may sprout in this garden.

These basic researches in gas discharges and the solid state also established certain research traditions in the less fundamental sections, including the engineering fields. For instance, our work on mercury lamps created an early interest in rachitis and the chemistry of vitamin D. The practical outcome was a process for the manufacture of vitamin D which became the starting point of our pharmaceutical activities. Work on a Stirling-type hot gas engine was tackled in an imaginative way; its first industrial application, however, was in an entirely different field, namely, that of air liquifiers.

Long-Term Policy

One might ask whether in the near future there may not develop again an entirely new era of research, profitable to the electrotechnical industry. This will, of course, depend on new discoveries and the progress of science. To discern these at an

early stage is of the utmost importance to the industry, and it is obvious that this is the main task and responsibility of the directors of research laboratory. They must, therefore, remain in close contact with the mainsprings of discoveries and scientific progress, which are still the universities and their leading scientists. In fact, Dr. Holst and the present directors, Drs. H. B. G. Casimir, H. Rina, and E. J. W. Verwey, are members of the Dutch Royal Academy of Sciences, and Dr. Casimir is also a Foreign Honorary Member of the American Academy of Arts and Sciences.

A close contact with the universities is highly desirable, not only for directors but also for the research staff in general. This contact is maintained also by the 4% of our academic staff who are concurrently also professors at the various universities of the Netherlands and is further promoted by a number of "alumni" of our laboratory, now full-time professors at universities throughout the country.

Internally the organization and atmosphere of the laboratory must be such that time and opportunities are provided to contemplate and visualize the future in relation to scientific progress. Informal discussion with the individual researchers in the lab and with scientists from outside must help management to form and to check on ideas and opinions.

Discussions at a high level on scientific progress under conditions undisturbed by the urgent calls of industry are extremely useful in this respect and must have priority. Such a discussion was held in 1958, in the form of a colloquium attended by a restricted number of theoretical physicists from the research laboratories of the various countries. The colloquium, which lasted a week, concerned itself solely with new topics in physics. It had a very stimulating effect. The physics director of our laboratory and an outstanding physicist from an American university took an active part. Another such meeting will be held in 1960, and more are planned on specific fields of research.

Apart from these meetings, which explore scientific progress in general, directors' conferences on a national and international

level are held every two years. The object of these conferences is to discuss research strategy, taking into consideration continuity, scope, and prospects from the technical and commercial points of view.

Short-Term Planning, Coordination, and Exchange

Quite in contrast to these long-term policy meetings are those which are needed to coordinate and communicate the results of research and discuss the tactics and trends in certain research fields. Generally speaking, the more limited the field under consideration and the fewer the people representing the parties, the more effective are the results.

In between short- and long-term meetings are the colloquia on a broader field. These are on a more informative basis. They are followed by the main group leaders concerned who form a research planning committee.

A very efficient procedure to strengthen the links between laboratories is the exchange of individual workers. We have had the most success with a period of at least one year. When we inaugurated a new research laboratory in Aachen, Germany, the entire scientific staff had a stay of more than one year in our laboratory at Eindhoven.

This exchange does not take place only between laboratories of affiliated companies, but has in recent years been extended to laboratories of other companies. If adequate facilities are provided, the work, usually of a fundamental character, frequently yields results worthy of publication. Apart from creating a better understanding, the opportunity to work under other conditions and to collaborate with people of different outlook has a stimulating influence.

Internal Laboratory Communication and Information

Within the laboratory, communication between the various disciplines must be stimulated. Dr. Holst was a great promotor

of an intimate mixing of physical and chemical schools of thought. Indeed, as early as the 'thirties he founded a fund, administered by the Royal Dutch Academy, which provides allowances to physicists who want to study chemistry for a period of one or two years, and to chemists to study physics. He applied this policy at the very start of solid state research in 1933, when the chemical staff of the laboratory was expanded. The newcomers were distributed individually in the various physics groups. Especially in the solid state division, a chemist often shares his room with a physicist. Frequently the group leadership is shared by a physicist and a chemist. This policy was extended to director level when Dr. Holst retired. As successors he nominated a triumvirate consisting of a physicist, a chemist, and an engineer. As associate directors of research there are again two physicists, two chemists and two engineers. The various disciplines are also represented in the same proportion in the forty group leaders and among the scientists in general. Indeed, many workers have, as it were, two responsibilities, one to their particular group leader and the other to the director of their particular scientific discipline.

I do not think we have anything of special interest as far as inter- and intragroup communication is concerned. Within the groups, comprising on the average, seven scientists, regular progress reports and literature reviews are generally held. Between some of the groups, problems of common interest are discussed jointly at intervals of one week to one month.

General information on the laboratory work is given by periodic short talks by staff members, a system we took over from Dr. C. G. Suits, vice president of General Electric Company. Every fortnight three of the younger scientists, preferably a chemist, a physicist, and an electrical or mechanical engineer, give a twenty minute review of some interesting aspects of work. These reviews are attended by most of the staff. They provide, if regularly followed, a pretty good idea of the work done in the laboratory and a guide as to who can best be consulted on problems outside one's group. In this same framework, senior staff and

group leaders present surveys and prospects of the work conducted in their groups.

Sometimes, circumstances can lead quite incidentally to an opportunity for a more general dissemination of information. Recently demonstrations, exhibits, and displays of recent laboratory achievements, set up for a visit by the company board, were shown next day to the entire staff after an introductory talk on the trends of research by the director. These and similar spontaneously organized events are highly appreciated, are stimulating, and have a beneficial effect on the atmosphere of the laboratory.

Before proceeding to the next section, I should mention for the sake of completeness the usual means of communication and information. These include brief bimonthly reports from the individual researcher, yearly reviews of the group leader to the director, preliminary and final laboratory reports which are exchanged with the affiliated research and development laboratories in other countries and courses for scientists and assistants.

Research Environment

These modes of communication will not be effective unless the environment is appropriate to carrying out of research for the specific requirements of the industry.

In an electrotechnical industry which is so dependent on scientific progress, it is the aim and purpose of the research laboratory not only to exploit but also to take an active, although modest, part in this process.

The effective execution of fundamental research is possible only in an environment which is conducive to satisfying the instinctive curiosity of the researchers without distracting their attention by the immediate needs of industry. This implies *freedom* of approach and publication and *freedom* from project budgeting and development needs.

It is clear that this imposes a high degree of responsibility

both on the management and their staff with respect to policy and publicity and also with respect to expenditure, for in the long run a certain field of research should yield results that are in reasonable proportion to the effort.

From the beginning, Dr. Holst, by fighting for these freedoms, and by keeping the research laboratories physically separated from the development laboratories, established an environment approaching that of a university, yet at the same time appropriate to the requirements of an industrial laboratory. The present directors have kept up this tradition. Indeed, the lab was honored in this respect by Dr. Mervin Kelly[1] when he wrote: "I believe that it is significant that the germanium triode and ferrite magnetic material, the two most important discoveries for electronics in the postwar years, were made in laboratories where there was a complete separation of research and development and where there had been a conscious and sustained effort to create an environment patterned after the academic."

Certainly, the academic environment of our laboratory has contributed to the success of Dr. Snoek's work and the invention of ferrites. However, the financial success of this work would have been far less if it had not been promptly followed up. In the case of ferrites, the inventor, Dr. Snoek, himself indicated the principal applications. With a certain aggressiveness he actually worked out one of them in detail and with great keenness safeguarded his invention in patents. However, research workers do not always combine the fun of research with the sport of application and patents. But there are many, even those who originally join our laboratory as a stepping stone to an academic career, who become gradually charmed and inspired by this combination. Few are the scientists who are entirely indifferent to the practical application of their ideas. However, scientists, although interested, may not themselves be the best persons to take care of practical aspects; it is then the task of management to put someone in charge of this follow-up.

The work of mathematicians and theoretical physicists, is not

so apt to lead directly to invention, yet this work may be of greater importance because it gives others the opportunity to invent. For this reason, it is unwise to remunerate separately especially spectacular practical achievements and inventions because this might draw people away from basic and long-term research into work showing more concrete results. Moreover, it would be the surest way of spoiling the atmosphere. Therefore, the tendency and policy in some countries in Europe to guarantee by law to researchers working for an industry a direct share in the profits of their patentable and exploitable inventions is neither in the interest of industry nor of the scientists themselves. Some of our managerial colleagues go to the extent of considering it a deplorable error perpetuated by well-intentioned officials unfamiliar with industrial research and the atmosphere of a research laboratory. The absence of legal regulations in our case shifts the responsibility to the management who must see to it that the staff receive a fair compensation for work they have done. But this applies to all work done and results achieved and must not be limited to the patentable inventions only.

There is much more to be said about the factors determining the environment, such as the role played by the group leaders in providing and promoting the right atmosphere, the help of a natural and well-balanced organization, and the influence of good relations with representatives of personnel and scientists. I will not deal with all these but will choose only one: that is the position and prospects of promotion of the outstanding scientist without or with only a limited group responsibility. It is our policy to give these researchers the same status as group leaders, with an appropriate salary. During the last decade this has been extended to the higher levels by the nomination of Scientific Advisors with the same status as the associate directors.

For those involved in applied research, serious damage can be done to the atmosphere and to the enthusiasm if the achievements of basic research are not quickly enough exploited by de-

velopment laboratories and manufacturing units. As I have mentioned, even those engaged in more fundamental studies are by no means indifferent in this respect. Deficiency of follow-up may be due to the fact that the development labs (at the present moreover understaffed) are hard-pressed by commercial departments in connection with immediate needs. It may, however, also be due to suspicions, engendered by previous experience, of overoptimism on the part of inventors. Sometimes, however, this "inertia" is due to overpessimism, conservatism, lack of courage, which all add up to lack of imagination on the part of those in development work.

One way to remedy this is to transfer to the development laboratories researchers who have worked long enough in research to appreciate the vision, the imagination, and the occasional overenthusiasm of the inventor.

This transfer means a sacrifice to the research laboratory but the returns of good collaboration with the development centers are worth it. Moreover, for those who feel in the long run more inclined to development or to a more direct responsibility for manufacture, it means a successful continuation of their scientific career. Most of the directors of the development centers of our main operational divisions and many of their deputies are "alumni" of our laboratory.

Follow-Up: Contact with Development Laboratories

Through this continuous transfer of experienced scientists from research to development, amounting to an average flow of 4% per year, good contact is maintained. Many of the people transferred keep informed on the research work in which they were originally interested and follow the central laboratory lectures on these subjects. On the other hand, the people of the central research laboratory remain in touch with the problems encountered in development and manufacture through the "alumni" of the research laboratory and, if care is taken that they

are not drawn from their research into development work, these contacts are beneficial to both.

For the sake of easy transfer it is considered an advantage that the research labs are situated not too far away from the development centers incorporated in the operational divisions to which they belong. The new central laboratories are, therefore, again planned near Eindhoven.

The central research laboratory acts also as a coordinating center between the various development centers. This is especially efficient because of the network of present and former research laboratory scientists.

In addition to these Eindhoven activities, the laboratory was instrumental in the setting up of international committees on technological development, an intermediate point between the international committees on manufacture and those of research. Like the research planning committee, they consist of two representatives of the various countries, meet once a year, and consider a rather restricted field. Although mainly development problems are discussed, the central research lab takes an active, if minor, part in the meetings.

Final Responsibility to the Company Board

In order to understand the relations between the top management body of the company and the research lab it must be pointed out that Dr. A. F. Philips, the architect of the prewar growth of the company, was always a pillar of strength and inspiration for Dr. Holst and the research laboratory. The present president and vice president, Mr. P. F. S. Otten and Mr. F. J. Philips, continue this enthusiastic support. The importance of the laboratory has been further recognized by the nomination and election of the physicist-director, Dr. Casimir, as a member of the company board. The final responsibility to this board is as follows:

The director of the laboratory, himself a member of the Board, keeps the latter informed at its weekly meetings. Occasionally long-term policy, including personnel questions and accom-

modation, is discussed at a meeting of this Board with the laboratory management, which consists of the three directors, their associates, and deputies. Recent research achievements are demonstrated.

Short-term planning, together with the development program of the individual operating divisions, is discussed in yearly meetings of the Board with the management of the laboratory and of the operating division concerned.

The three laboratory directors advise the Board on certain policy matters, such as contracts and licenses, at regular biweekly meetings in which the management of the operating divisions and representatives from the development, patent, and legal departments also take part. These meetings are again advised and informed by subcommittees, constituted along similar lines for each product field.

The Future

The rise in the average age of the world population, especially in the less-developed countries, and the present rapid rise in standards of living are made possible by the progress of science and its application, through research, by industry. On the other hand, the rapid expansion of industry is promoted by the needs of the growing population and the urge towards a higher standard of living. This results in an accelerating effect, limited at the present time mainly by the shortage of able scientists to carry out the necessary research. In the last 30 years or so research personnel strength has been growing at an average rate of 6% per year.

This implies a doubling in numbers every twelve years. Obviously, this cannot continue indefinitely, but in the coming decades it may still be possible, by more efficient and inspiring education, especially at college level, to get the required number of scientists.

The shortage of personnel stresses the importance to the overall effort in industry of carrying out research as a whole efficiently;

for example, not too much duplication of work should be done without coordination. Within a laboratory this is certainly attainable. Within a group of research laboratories in various countries it implies self-discipline and mutual confidence between the various labs to leave a particular field of research to the one selected. Between competitors rigorous coordination is, of course, impossible and undesirable. Yet there exists in the western world a growing realization that scientific cooperation between industrial research labs is to the advantage of all concerned. The same is true of cooperation between industrial labs and government establishments. We often help others with facilities not available elsewhere but on the other hand we ourselves are dependent on the help of reactor establishments of the government for irradiation experiments that cannot be done in our cyclotron or one of our high voltage generators.

Within a laboratory the growing complexity of research equipment has yet another effect. It is changing the environment by making one more dependent on the collaboration of colleagues for services such as x-ray diffraction, chemical analysis and synthesis, and computing. Dr. Holst pointed out that the part played by the members of these services is easily overlooked. In order to maintain good collaboration and a good atmosphere, great care should be taken to give full credit to their services and contributions not merely by acknowledgements, but, where appropriate, by joint publications. In general, it is very important, especially with a growing population in the lab, to maintain unrestricted openness between colleagues, regardless of any possible success or credit; mutual trust in this matter should be an unwritten law in the laboratory.

Another problem of the growing laboratory is that of keeping the environment as much as possible like that of a small community, while at the same time profiting from the facilities of a large one. This may be done by replacing the overall contacts of the small community by an equivalent pattern of personal contacts between the individual scientist and his colleagues in adjacent fields and service departments, from the laboratory director to

and the workshop mechanic. It will be mainly the task of the group leaders to stimulate and activate these contacts. It is also of vital importance that achievements of the individual scientist should be reported to his director.

With expansion of industry as a whole, appreciation and understanding of the structure of the company and contact with its elements must not be lost. Our company, therefore, is extending its introductory and management-development courses, where people of diverse disciplines (including commerce, law, and economics) meet and get to know and appreciate each other and each other's function in the company. In this way, the company hopes to promote positive cooperation in, for example, the product teams each of which consists, of a research worker, a technologist, a factory engineer and a commercial man. Preparedness and permission of individual members to overlap each other's responsibilities are essential for the success of these teams.

It is obvious that with the growing influence of science in industry and in the outside world the attitude of the researcher is changing. The scientist of today is in some respects more self-confident and in addition, he feels more responsible for the role played by the laboratory as a group. The management of the laboratory has to reckon with and use this change to the benefit of the research community.

We must be prepared to meet not only changes in the attitude of researchers but also changes in the attitude to research itself. We believe we have at the moment the right balance in the laboratory between basic and related applied research to give a fruitful symbiosis. Will it be desirable in the future, by analogy with the separation of R&D, to again separate fundamental and related applied research?

Another question: How can we provide an environment where the mental strains forthcoming from a community with a high concentration of intellect, are buffered to the optimum for effective research? A delicate balance between the personal and the scientific stimulus is required; how can this best be achieved?

Are the sciences of human behavior such as psychology and sociology, sufficiently developed to help us answer these questions? We have our doubts. However, on these questions we have recently contacted the company's psychological department. Since the United States is more advanced in these sciences than we are, I hope to get some answers and suggestions from you.

On the other hand I think it would be interesting for social scientists to follow and study the environment and management of research labs, because this may lead to improved management practices in general. Communities such as research laboratories are not only advanced in science but also progressive in granting freedom and delegating responsibility; they offer ideal opportunities for self-expression, not only scientifically but also in the social and ethical sense, opportunities which, taken with humility, are related to the highest aspirations of humanity.

The publication of this talk gives me the opportunity to thank Drs. H. B. G. Casimir, G. Holst, E. Oosterhuis, and E. J. W. Verwey for their criticism and valuable remarks, and Mr. C. M. Hargreaves for his corrections to my English.

Reference

1. Kelly, M., *I.R.E. Natl. Convention Record*, **1953**, Part 6, 133.

CREATIVITY IN RESEARCH ORGANIZATIONS

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Many articles have been written about techniques for promoting creativity. Most of these miss the main point—that creativity will appear when there is a genuine demand for it. It cannot be evoked by superficial techniques, plans, or polite gestures. Perhaps this is fortunate, since few organizations or administrators really desire it. Nothing is more calculated to upset the smoothly-functioning routine of an organization than an upsurge of original ideas and proposals. Management must make new and difficult decisions; people throughout the organization are disturbed at the prospect of having to change their comfortable habits and patterns of work.

What do we mean by creativity? Presumably this is the faculty of originating new ideas. But is any idea really new? Each of us has in his mind a store of remembered images, pieces of information, rules, concepts. These are arranged in some sort of order and are usually associated with each other in organized groupings. The creative person does not so much originate new ideas as combine old ones in a new way to achieve a surprisingly effective new result. I like the definition of originality which Dr. Foster D. Snell, often uses; "Originality is applying knowledge which you gained in one field to another field."

Paradoxically, therefore, we literally cannot *learn* to be crea-

tive; we must rather unlearn something. We must somehow obliterate the walls between the conventional groupings of concepts in our own minds. We must break down the barriers which keep us from bringing together an equation we learned at school, a queer color change in the flask before us, and somebody's offhand remark about the low price of some chemical to see the possibility of new, money-saving process change. A man might have all the knowledge in the Congressional Library stored in his mind and yet be utterly devoid of creativity if the ideas merely remain neatly in place (as they do in the library). Children are highly creative. They have not yet learned to organize their ideas. Their creativity is not too fruitful because they don't have enough ideas and knowledge. As they grow up they learn more and more, but their knowledge becomes more rigidly organized and compartmentalized. The optimum of creativity will be passed when the second process overtakes the first.

Creative thought often takes place on the subconscious level, so that the final concept may seem to spring full-blown to the conscious mind. The role of the conscious intellect usually consists not in forming the creative idea but in examining it for validity and probable usefulness. From among many ideas which are conceived, one must select the few that are promising enough to merit careful analysis and practical trial. The ocean contains gold worth countless billions of dollars, but no one has become rich by extracting this gold. It exists in so highly dilute a form that the effort does not pay.

Here, then, are three requirements for creativity: one must know many things (preferably in many different areas); one must be able to shuffle this knowledge about, making new combinations or syntheses; and one must apply intelligent judgment to the resultant ideas. There is yet one additional essential requirement for any type of human behavior—that of *adequate stimulus or motivation*. I may be able to stand on my head or to sing Chinese songs, but that does not mean that I will do so—at least not in public. I will do these things if the people around me

want me to do them; if they will reward me with approval, recognition, or money. I will not do them if I find that they attract only annoyance or hostility. Similarly, if I find that when I present new ideas I get no response, or merely some formal organizational reflex acknowledgement from my superiors, or if I find that my co-workers are suspicious or resentful or feel that I'm stepping on their toes, I'll probably take the hint after a while. Even if management tells me how much it values new ideas and creative thinking, I'll recognize that they don't mean it.

Creativity, therefore, depends in large measure on whether the environment encourages it or is hostile to it. But surely this cannot be right. What about men who have worked steadily, painfully at highly creative tasks alone, ignored by the world or even in the face of hostility of their peers and neighbors? What about Spinoza, Luther, Mendel? Some such as these live in every age, but they are few. The rest of us are almost pitifully sensitive to the opinions and the expectations of our fellows and even more so to those of our superiors. We want the security, the emotional and financial rewards that come from being well regarded, liked, and respected and keeping out of trouble. The average person working in an environment where original thinking is taboo will soon stop presenting new ideas. After a while he will no longer even conceive any new ideas—that sort of thing will have been trained out of him.

Some people, it is true, have not only the capacity but a positive need for creative self-expression. They cannot remain satisfied to go along doing routine work; they envision new methods, new products, new techniques, and they have a burning desire to get these things tried out. Probably creativity cannot be fully trained out of such people even in the most rigid and uncreative organization. It can, and often is, transmuted in large measure into bitterness by frustration.

Many such highly creative people seem somewhat offbeat—restless, moody, asocial, or nonconformist in various ways. They may lack the tact and easy-going good fellowship that is so much

valued in many large business organizations. This does not mean that detached or nonconformist individuals are necessarily creative—only a small minority are. However, an organization which tries to screen out people who seem unusual and hire only pleasant, social "nice guy" types will probably screen out much of the really creative talent. Possibly the creative person is often driven to create by some inner tension or restlessness, some desire for self-fulfillment which the average person discharges in playing golf, driving the family to the seashore, and chatting over a card table. The company which advertised of its research laboratories "No geniuses here—just ordinary Americans at work" is unfortunate if its advertisement was accurate. Most likely however, it was not accurate; it was some executive's idea of what would constitute a favorable public image.

We know that remarkable upsurges of creative thought and action have occurred at certain times and places. Periclean Athens and Italy in the Renaissance are prime examples. Those who lived in such times cannot have been unique by heredity; when the creative wave passed, their descendents no longer created. Perhaps some day psychologists or historians will explain this phenomenon. But without understanding it, one can sense its quality. It is like a fresh wind sweeping across the fields and through the cities. There is a sense of excitement—so much to do, so much to know. The world seems young and full of challenges—challenges which an able man can meet, can grapple with and win through. There is argument, conflict of opinion, new men rising into prominence everywhere, confusion, intellectual adventure. The old traditions and religions are attacked, but they do not necessarily succumb—they may put out new leaves like a tree in spring and come to life again.

On a smaller scale, we have the same thing in research organizations and in businesses. A few palpitate with the clash of ideas, the seemingly confusing or noisy disorder and the sense of excitement and achievement which is so often the concommitant of creativity. The great majority do not—they move along smoothly,

well-organized machines in which each cog moves only as impelled by the cog above and only to turn the cog below. The unwritten motto on every wall is "Don't rock the boat." The cogs rotate smoothly; the machine functions well; times are prosperous, profits are increasing; just keep in line, don't step on anyone's toes, and you'll be all right.

In the long run, any organization takes its tone from the people at the top—I say in the long run because even top managers cannot change the habits and spirit of an organization overnight. Those things have a certain stubbornness and persistence. But over a period of time it can be done. Usually, however, a noncreative organization moves toward creative action only when it gets into trouble that brings new people to the top or jolts the old managers into action. Otherwise it remains its old, smoothly-functioning sterile self (why rock the boat?).

What type of manager will build and effectively direct a creative organization? The prime qualities would seem to include curiosity, liveliness, an aggressive desire to accomplish things rather than merely to administer routinely, a positive thirst for the new idea, the new method, the new product that will put their company way out in front. They must be good listeners, willing to have people argue things out, willing to have their people venture boldly and make mistakes, willing to cut across channels, to cut red tape, to value more highly the living flame of thought and achievement than the formalities of protocol and propriety. This attitude should not be confused with the propensity of some executives to discuss problems endlessly for fear of making a decision. The decisions must be made firmly, but after—not before—the process of discussing, arguing, and exploring has enriched and stimulated the mind of the executive.

Creative management of this type is rare. It demands unusual qualities of leadership, patience, and judgement which may not be required of the individual research man working along at his own project. Regarding such leadership in its highest form, the Chinese sage Lao Tse said: "Of the second-rate rulers, people

speak respectfully saying, 'He has done this, he has done that.' Of the first-rate rulers they do not say this. They say, 'we have done it all ourselves'."

There are three common reasons why top management may not want creativity. One is that it seems an unnecessary burden. If business is good, if the company enjoys a strong financial position and is making good profits, there is great temptation on the part of management to coast along. Why get involved in discussions and tough decisions? Why take risks on new ideas when everything is going so well? Top executives may develop an almost superstitious aversion to change under such conditions—they may fear that any change in products or methods might somehow break the spell. It is no accident that the recent compact-car revolution in the automobile industry was initiated by the marginal, struggling American Motors Company rather than by prosperous General Motors or Ford.

A second reason may be that the top man is himself a very forceful and creative person. He may want an organization which carries out his ideas smoothly and efficiently rather than one which originates ideas. If he is a very able person, results may be quite good for a long while. Eventually, when he is gone, the organization may lose its ability to accomplish. Sometimes even while the top man remains this can happen. He grows older, loses his flexibility and flair but retains his stubbornness, surrounds himself with yes-men and gets rid of anyone who disagrees with him. The organization heads downhill.

A third reason may be that creativity in one area has stifled creativity in another. Research, production, marketing, and finance are all essential factors in modern industry. If top management overemphasizes any one of these, it may build up a talented, creative group in that area while relegating people in the other areas to servant status. A business may have a brilliantly creative research department and yet be unsuccessful if its marketing efforts are ineffective and expensive. In an organization dominated by advertising and marketing people, research may be expected

merely to implement the specific requests which those people make, often for minor improvements or "gimmicks." Original suggestions by research people are not looked upon with favor.

The utmost in creative achievement can be attained from many creative people only if they are given significant and important jobs with a good deal of freedom to follow their own approaches, perhaps to get into trouble and get themselves out of it. A salient characteristic of creative organizations is that the manager seeks men who can achieve, gives them important, challenging assignments, and demands results. In many noncreative organizations the manager seeks men who will follow detailed orders, gives them fragments of jobs to do, tells them exactly how to do these, and requires only strict compliance with orders.

This article does not attempt to suggest techniques for improving creativity. Its theme is rather that if management really wants achievement, originality, the bold idea, it will get them. If it doesn't, it will not get them, and the "techniques" which it institutes will be recognized for what they are—a sort of window dressing not intended to be taken seriously. Some organizations have set up officially-sponsored "brainstorming" sessions. They probably are not of much use. In an uncreative organization they will lead nowhere. In a creative organization, that sort of thing is going on informally all the time and probably does not need to be organized.

Some executives feel that research people must be handled with toughness, while others seem to believe that research men are sensitive plants who must be handled very gently. If carried out as a general policy, each of these misses the point. Indeed these attitudes are sometimes two sides of the same coin and indicate a lack of real respect for research and an anxious desire by the executive to avoid trouble rather than to achieve. The important thing is the kind of "toughness" and the kind of "gentleness" displayed. A management which really wants original ideas and achievement will be tough in demanding these things, in insisting on meaningful accomplishment, and will not be satisfied with an

TABLE I

Uncreative	Creative
Manager gives detailed orders for limited operations; he puts the pieces together.	Able research men in the ranks are assigned important jobs and expected to carry them through.
Laboratories meticulously neat.	Laboratories often untidy and cluttered.
People always advance proposals through proper channels.	People go to anyone who can help.
People never argue about technical matters before the manager.	Technical argument is common and stimulated by the manager.
Manager gets all information and advice through channels.	Manager asks questions, discusses problems with research men in the ranks.
Middle management is composed of smooth "nice guys."	Middle management is aggressive, hard-driving.
Company etiquette, protocol, following rules meticulously highly important.	Formalities are considered much less important than productivity.
People seldom work out of hours or stay late to discuss technical problems.	People often stay over to work or to discuss.
Staff reluctant to ask questions or make statements which might seem foolish at meetings.	Nearly everyone feels quite free to speak.
There are many large formal meetings and committees.	Meetings are usually small and informal.
Nearly all the work is to carry out specific orders by top management.	Much of the work originates in ideas contributed by the research people.
Most effort is directed toward achieving minor improvements, small cost savings, or "gimmicks."	Most effort is on major problems whose solution would improve the company's position decisively.
Creative but "off-beat" people become bitter and frustrated or leave.	Such people usually remain and contribute a good deal.
At lunch conversation centers around automobiles and golf scores.	At lunch conversation centers around technical problems.
Reports are long, carefully edited, polished, and late.	Reports are usually prompt, informal, and pointed.
Company generally follows its competitors' lead in new fields.	Company often develops new important products or processes.

employee merely because he obeys all the rules and speaks ingratiatingly to the boss. However, it will respect, appreciate and handsomely reward unusual achievement to a degree which some executives might consider overgenerous and coddling. A management which does not want creativity will often be "tough" in demanding that employees obey all rules meticulously and do precisely what they are told exactly as they are told to do it. It may be gentle in that it does not seem to demand or even expect anything more than compliance with rules and detailed orders. Many executives who pride themselves in being tough are actually very soft and undemanding. They do not want anything more of their subordinates than that they follow orders. Men who want security and have little creative ability like to work for such executives.

There are certain hallmarks of creative and uncreative research organizations. Some of the salient differences are listed in Table I.

I do not suggest that these features are causes of creativity or sterility; rather, most of them are symptoms. They occur not so much by conscious choice of the management as by psychological consequences of persistent basic management attitudes. They cannot be evoked in a vacuum without reference to those attitudes. Creativity is not a mechanical process which can be ordered or taught. It is, like love, a free gift of the spirit. It is evoked not by skillful manipulation, but by management presenting people with significant challenges; by management seeking, demanding, thirsting for creative ideas.

PROCEEDINGS OF INDUSTRIAL RESEARCH INSTITUTE STUDY GROUP MEETINGS. NUMBER 2.* JOB STATUS AS AN AWARD FOR SCIENTIFIC AND ADMINISTRATIVE ACCOMPLISHMENT

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Introduction

The topic reported in these Proceedings was the one selected by a special committee of the Institute to determine the feasibility and value of study group meetings. The two conferences on the subject were led by Mr. J. Harold Perrine, Administrative Manager, Research and Engineering Department, Sun Oil Company, and Mr. Galen J. Wilson, Director of Research, The National Cash Register Company.

The agenda included three major subjects:

Position analysis (What is it? How used and on whom?)

Scientific ladders (Are they working? What are the essentials for use?)

* The circumstances which led to the formation of the Research Management Study Group Conferences and their objectives have been covered by Vaughn.[1]

Recognition and awards (What to recognize? How to identify the right man in a group?)

Position Analysis (or Job Description) Definition

For discussion purposes, position analysis was defined as a study which provides a complete understanding of the objectives and content of a position, independent of the incumbent, by adequately defining its functions, responsibilities, relationships, authority, and accountability.

It soon developed there are two schools of thought on job descriptions, differing quite fundamentally in their use of them as well as their procedure for writing such descriptions. One school is in favor of *specific,* detailed position analyses for implementing organizational planning and control. The other school is in favor of *broad,* general job classifications, flexible enough to accommodate a creative professional person.

Expositions of these viewpoints, each presented by a participant of the meeting, have been published previously.[2,3]

The advantages of specific, detailed job descriptions were summarized as follows:

(*1*) Convenient prerequisite for using job status as a reward for achievement
(*2*) Basis for external and internal comparisons for compensation purposes
(*3*) Basis for appraisal of performance
(*4*) Aid to the development of management
(*5*) Useful in recruiting, hiring, and placement
(*6*) Basis for orienting new employees
(*7*) Basis for promotion
(*8*) Basis for self-understanding
(*9*) Assist in clarification of the organization and aid in organizational planning

Disadvantages of specific position analysis brought out by the discussions were:

(*1*) A large initial investment of money and manpower is required.
(*2*) Continuous revision and implementation are needed.
(*3*) Duties of new personnel may have to be stated in vague terms (this also applies to older employees on ocasion).

The proponents of broad, general job classifications claimed that they aid in placing people in jobs that fit their occupations and abilities; however, they protested these should not be broken down into labor grades and used as merit classifications. A number of the conferees, however, admitted they wanted job descriptions made specific enough to aid in salary administration.

At this point the question of semantics enters the problem. How is it possible to compare the status of people in like positions in different companies as long as we have no standard job titles common to all industries and among all categories of professional people? Men of equal training, ability, and experience may be classified as Research Chemists by one firm, as Senior Scientists by another, and as Members of the Technical Staff by a third.

The conferees agreed that the attainment of uniform job titles throughout industry could be extremely helpful, but that the goal is probably unattainable. However, the adherents of both schools of thought agreed that it should be possible to write down the broad functions or basic objectives in and the responsibilities of a position. They also agreed that the details of the major responsibilities assigned to a position can be agreed upon. Undoubtedly, the serious language problem inhibits flow of personnel information among companies, but broad classifications should aid greatly in evaluating the worth of a scientist or professional man in any company he may choose to join.

It was pointed out that in university life the titles of professional people have meaning to the general public as well as to their colleagues, but this happy state of affairs has taken centuries to

attain. It seems too much to hope that diverse industries can realize a like uniformity of titles in our lifetime. In many cases, it is even impossible to arrive at uniform titles in the various divisions of some of our larger companies. Titles are too involved in history, tradition, and their own peculiar evolution.

As a result of the study groups, a questionnaire was agreed upon which would be sent to individual members of the IRI, the replies being used to prepare a glossary of terms describing different levels of responsibility in our separate types of industries. This is the necessary first step preceding analysis of the positions.

The Research Spectrum: A Basis for Orientation

A basic concept which helps resolve a number of difficulties is that of the research spectrum. Research, as conducted in the industrial world, can be directed to a number of different objectives.

Basic research, regardless of the discipline involved, is *divergent* in nature: discoveries in one discipline can lead to useful applications in many fields. Technical service research, on the other hand, is of a *convergent* nature: specific problems in a relatively narrow area must be solved by the use of any pertinent science or technique. Between these two extremes lies the whole spectrum of research types. Some of the research classifications in this range, reading from the divergent to the convergent end, are: basic, applied, advanced engineering, development engineering, advanced design engineering, manufacturing, technical service, product improvement. Only a few of our largest industrial firms conduct research over this entire spectrum; most companies confine themselves to the convergent types of research.

If we realize and appreciate that basic research is of a divergent nature, whereas advanced engineering and development research are convergent, and that individuals and groups working in these different areas necessarily have an entirely different philosophy and outlook upon their jobs, then we can appreciate and understand the need for different types of organizational control.

Most of the conferees agreed that, in the light of this principle, broad job descriptions would be quite adequate for basic research workers, whereas much more specific and detailed descriptions would be needed for people working in the convergent research areas. This guiding principle also proved to be of use in understanding the different attitudes, revealed in subsequent meetings, toward creativity and responsibilities of the first line supervisor in a research organization.

Most of the participants agreed that, although job descriptions are good for the lower level classifications of their research people, at the higher levels they are too restrictive a tool. Top performance goes beyond any one description that can be written. The consensus was that job descriptions *per se* are absolutely worthless and unrealistic for evaluating the contributions of experienced personnel who have shown that they are creative and can contribute far beyond their cost to a company's prosperity.

Some people felt that if we should change the title from "job description" to "position analysis" or "function analysis" we would get away from the implication of salary classification attached to the words job description. Then, in a function analysis scheme, we can incorporate the philosophy of management for a broad research program. An additional advantage would be that the need for costly and constant revision of innumerable job descriptions would be eliminated.

In summary, when the different types of research done in our industrial firms are kept in mind and the quality of people we are talking about is kept in line with their research function, there is little disagreement about how to write position analyses or to use them in administering research.

Scientific Ladders: What They Are and How They Work

Most industrial research organizations now have dual routes of advancement for their professional people. The oldest and best known of these is the administrative ladder, but in recent years,

the parallel scientific or professional ladder has arisen. Some companies even have a third ladder for personnel advancement, an administrative one involving only nontechnical research staff work without supervisory responsibilities. The study groups confined their discussions almost entirely to the first two mentioned.

In many companies the only means of advancement has, of course, been the administrative ladder; this has been widely criticized as a device for making nonscientists out of scientists. To avoid this, a number of research managements created the professional (or scientific) ladder, conceived so that a man may advance in scientific stature and prestige, and economically as well as socially, without having to become an administrator and nonscientist. This concept is growing in favor among industrial research groups.

For clarification of the discussion to follow, the titles used on the parallel administrative and professional ladders by the research division of a typical large company are shown in Table I. Each

TABLE I

Administrative ladder	Professional ladder
Vice President and General Manager	Senior Research Associate
Manager	Research Associate
Director of Research	Senior Research Chemist
Assistant Director of Research	Research Chemist
Supervisor of Research	Senior Chemist
Assistant Supervisor of Research	Chemist
Group Leader	Associate Chemist

title listed carries a range of salary levels, and there is considerable overlapping of the different levels. Salaries ranging higher than the group leaders' are administered by the Executive Committee of the company, and the top two professional levels—Research Associate and Senior Research Associate—fall on the executive payrolls.

Creation of a professional ladder, and assignment of all non-administrative scientists to a particular rung of it, was accepted very well by all the persons involved at this company. This favorable acceptance was attributed to a thorough job evaluation appraisal, made by each scientist in consultation with his supervisors, that preceded announcement of the new system. Every man knew by announcement time exactly where he stood in the dual hierarchy, and felt he had a part in its formulation.

In the past, the use and availability of a professional ladder frequently has been abused, and the mistakes made are now recognized as pitfalls to be avoided. One of the most common research management errors mentioned in these meetings was that the professional ladder often was a dumping ground for personnel problems, whereas, it should never be used as a means of shelving a man. A second pitfall is that some people find such an isolated position a lonely one and soon get a feeling of rejection. A third difficulty is that the titles given on this ladder are not always recognized for their true importance by the scientists' friends and neighbors. Another thorny problem is judging the proper number of people to put on a given rung of a scientific ladder; it is quite easy to be injudicious in either direction, and this means more trouble for the research organization. Finally, it was noted that a few men, on attaining the higher levels of the professional ladder, tend to loaf and lose their productivity.

Guest speakers at the study groups pointed out the great difficulty of appraising performances of individuals on the professional ladder. Oftentimes the value of advanced research work cannot, by its very nature, become apparent for many years. No one in the organization is really qualified to judge the worth of such contributions, and, furthermore, who is to say how much accomplishment constitutes adequate or superlative performance?

The discussion of professional ladders soon resolved itself into a consideration of means for making the professional ladder work. To help the group with this problem, guest speakers related their experiences on both types of ladders. One speaker

found it desirable because of conditions arising from the growth of the company, to transfer from a relatively high position on the administrative ladder to a similar level on the scientific ladder. He stated that the transfer had no apparent effect on prestige or on the status of his family in the community. Another speaker described the scientific ladder in his company as in the formative stage. His own duties included high-level scientific, consultant, and administrative work.

To summarize the information gathered on scientific ladders, it is apparent they have been abused in the past but that they are working now in a number of industrial research organizations. They have definite promise for a much greater usefulness in the future. It is most obvious that the highest administrative integrity is necessary to make them function properly. One suggestion often made for improving the status and obvious prestige of men on the professional ladder is to supply them with their own separate laboratory facilities and specialized services.

Recognition and Awards

Identification of the Deserving Scientist

The problem of appraising the performance of a professional person is a difficult one and there are many approaches to it. They range all the way from elaborate appraisal systems, involving point grades on a large number of different factors, to a very informal method. Factors most frequently mentioned by the study groups for appraisal were the man's productivity, his facility in oral and written expression, the technical judgment he has displayed, his publications, and the number and quality of patents assigned to him. Most participants felt that point ratings are too susceptible to error and warped evaluation. The primary people involved in rating a man are the two levels of management immediately above him; his section leader's overall judgment is the principal witness in evaluating the deserving scientist.

Some of the conferees pointed out that it is a mistake to appraise a man's performance at the same time his salary is being reviewed, since a man's boss tends to put a halo around his worker at this time in order to get approval for the raise he wants for his man.

One person pointed out the difference between recognition of employees by management, who base it entirely on dollars, and recognition by a man's peers. His co-workers tend to establish a so-called professional "peck order" which is determined by the people themselves, not by management opinion.

The criterion of profits as a measure of accomplishment is a very difficult one to apply because it must be made over a long period of time.

The group listed the following points as criteria of successful accomplishment, though not necessarily in the order of their importance.

(*1*) Number and quality of patents
(*2*) Number and quality of publications
(*3*) Other indications of productivity
(*4*) Opinions of peers and superiors
(*5*) Participation in company seminars
(*6*) Maturity, judgment, objectivity
(*7*) Effectiveness as a communicator
(*8*) Dedication and enthusiasm
(*9*) Technical ingenuity
(*10*) Perceptiveness
(*11*) Willingness to be controversial
(*12*) Creativity
(*13*) Keeps abreast of his field (enthusiastically)

There are probably other criteria for identifying deserving men, but the important consideration is to eliminate personal bias from the judgment and to compare individuals with others in the same category of professional work.

How to Reward the Deserving Scientist

All attendees at the study group meetings agreed that the first and foremost reward for a deserving scientist must be a monetary one. All other kinds of recognition are far behind this single, over-riding consideration. Monetary awards take several forms, however, and these were categorized as the rate of advance, special bonuses, stock options, stock purchase plans. Other means for rewarding performance listed by the group were:

(*1*) Invitations to speak, or to write for house organs
(*2*) Special leaves at full pay
(*3*) Attendance at special meetings (representation on committees)
(*4*) Professional freedoms:
  (*a*) To publish
  (*b*) Time off for purely professional chores
  (*c*) Choice of research problems
(*5*) Titles (promotion to the scientific or professional ladder)
(*6*) Personal publicity (sponsored chairs or lecture series at universities in the name of the scientist)
(*7*) Trappings (special parking and dining room privileges; special office or secretarial help)
(*8*) Personal commendation or approbation

There are a number of miscellaneous means of rewarding scientists. For example, one representative said his company sends chosen people to technical symposia held at fashionable resorts for several days; these social-business contacts between management and research have been very effective. Another company has no formal rule to the effect but they try to send new technical employees to a meeting the first year they are with the company, regardless of their degree level. Another company uses junior technical men for customer contacts; the scientists regard this as a privilege rather than a chore because it helps them to become known throughout the industry. Still another company uses its scientists

for supervising fellowships in universities where they have taken their own degrees; this also aids in recruiting new men, though often no formal effort is made to do this. Some companies tie in the length of vacations with job status, regardless of a man's seniority in the company.

Sense of the Meetings

Industrial research and administration has adopted, to its detriment, too many of the policies and practices of the production organizations with which they are associated. This occurred because of the domination by company personnel groups, oriented in industrial experience, who believe that all functions of a company must be administered through one common system.

Experienced research organizations have come to realize the supreme importance of the fact that research has different goals from production. Therefore, they have developed personnel policies more suited to the special peculiarities of the research function.

The main product of research is ideas. These come from creative individuals and cannot be brought into existence by management edict. Freedom to think and perform, without restrictions or deadlines, is needed by the researcher.

Rigid structuring of a research organization with detailed individual job descriptions, which eventually become related by rather arbitrary point systems to salary administration, do not give the required freedom to the individual. Research personnel can, however, be grouped into several levels of competence, and these levels then can be related to salary grades used by other divisions of the company. The operation of this principle may be extended to include other companies in the same business and, ultimately, to cover the professional people in all categories of industry.

Programming of research should, ideally, come from the individual to the top through an appraisal system which avoids specific job descriptions. At appraisal time the program planned for the previous year can be discussed and accomplishments compared

with goals. Then, with the help of the supervisor, the goals and program for the coming year can be developed and recorded. In this way, the program of the laboratory is integrated, with supervisory guidance, into the long-range goals of the company, and the job to be accomplished by each individual is created and described by the man himself.

Professional ladders, permitting advancement of scientists without their assuming administrative burdens, are finding increased favor among industrial research organizations. Pitfalls impeding their proper use in the past are now well known, and the importance of administrative integrity in avoiding them is recognized.

All conferees felt they benefited greatly from the exchange of ideas and experiences. Their pooled efforts produced a very complete list of criteria for recognizing individual accomplishment. Means of rewarding deserving scientists were also thoroughly delineated. New material was added to the presently available knowledge of job status as an award for scientific and administrative accomplishment.

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JOB STATUS FOR THE RESEARCH SCIENTIST

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In recognition of the need to keep able research scientists at the laboratory bench rather than paradoxically rewarding their merit by removing them to an administrative desk, many companies have set up a special technical ladder of advancement. This research ladder, or senior scientist program as it is sometimes called, is intended to supplement the usual administrative organization chart. To define the status of these research positions and stress their equality to administrative jobs, the two progressions are often represented as in Figure 1.

While the company may be sincere in its effort to reward the gifted scientist who has neither desire nor talent for administration by establishing salary ranges on a par with the management scale, they may, somewhat self-consciously, overemphasize the equivalency in status of research and administrative jobs. This overemphasis does more harm than good because (*1*) the two ladders are, in fact, not equivalent; and (*2*) the stress on equivalence provokes comparisons that ought not to arise. The result is that too often undue attention is paid to "status symbols" such as office size and furnishings, secretarial service, reserved parking privileges, etc. Since salaries are not made public, it is these minor trappings which give the aura of status in the organization.

It would be far better if the qualifications, needs, and goals

within the technical and administrative groups were recognized as distinct and emphasis placed on the uniqueness of the technical ladder and the special opportunities provided in its positions.

In industries such as electronics, where basic research has demonstrated its worth, the larger companies have established separate basic research laboratories. In these laboratories, com-

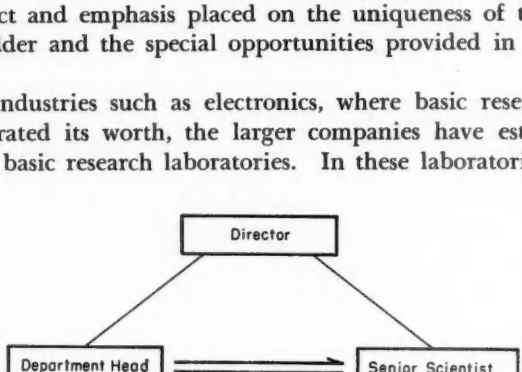

Figure 1.

posed of men concerned solely with pure science, the criterion of professional competence is sufficient to define the status of a scientist. The universal need to feel that he and his work are important is not difficult to satisfy for the research man when the attention of his colleagues and the laboratory director are focused on that area.

The problems of status and job satisfaction are much more pronounced for the scientist in the technical ladder when fundamental research, applied research, and development programs are combined in a single laboratory. Here, the scientist is forced to compete with widely divergent groups for the available laboratory services, for the attention of the director, and for recognition from his co-workers. No matter how well-adjusted, self-assured, and independent the research scientist, his morale, and with it his value, will suffer unless care is taken to furnish the opportunities for job satisfaction directed to his particular needs. This job satisfaction cannot be supplied solely by an arbitrary definition of status on an organization chart. The forced competition will quickly show up any difference between theoretical and actual status.

I stated previously that the equivalence of administrative and technical ladders emphasized by Figure 1 was not true. To illustrate this difference I have compared in Figure 2 the actual administrative organization of a typical development department within the technical organization. Consider first, the meaning of the blocks in the administrative group. Each block represents a particular and well-defined job. Each group has specific areas of responsibility, and the group leader administers and directs that group. If a man leaves the position of group leader, there is a definite vacancy on the chart. Until the job is filled, that group is without a leader. Each job in such an organization has status in itself, independent of the man holding that position.

Further, the lines between blocks in the administrative chart have two meanings. First, they designate the responsibility and authority under each position. The section head, for example, directs the group leaders and in turn receives direction from the department head. Second, the lines represent the normal path of advancement. Promotion, therefore, moves a man to a status which gives him authority over his former grade. In this sense, the promotion follows the military, which literally wears its status on its sleeve.

One final point, before leaving the administrative ladder, is to note that it converges in moving upward. Thus, each higher position covers a broader area of responsibility. The man, if promoted, is forced to widen his horizons, to become involved in other, less familiar fields. He is brought into contact with new groups of people. The transition is abrupt and is accompanied by physical changes, such as moving to a different office. These changes cannot help but stimulate the man and define the promotion clearly to others as well as himself.

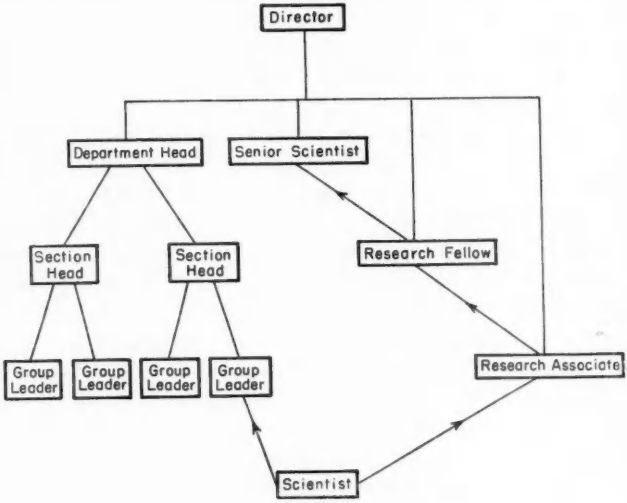

Figure 2.

Turning now to the technical positions of Figure 2, the meaning of the blocks is quite different. These blocks are not jobs to be filled but rather titles to be awarded. If a research fellow leaves his position, it does not create a vacancy in that position on the chart. True, the project he was working on may be held up, but there is no reason that the work could not be con-

tinued by a research associate or by a senior scientist. The titles by themselves carry no evident function. In the technical group it is the man who gives status to the job.

Furthermore, the lines between these blocks have only one meaning—path of advancement. They do not represent authority over, nor responsibility for, the positions under them. Each job is a separate entity, otherwise the technical group would become an administrative ladder. Laboratory technicians may be assigned to the research scientists, but generally the number is rigidly restricted, first, to avoid burdening the scientist with administration, and second, to prevent the number of technicians assigned from becoming a symbol of status.

The changes accompanying promotion in the technical group are much less clear-cut than in the administrative ladder. The promotion is certainly accompanied by an increase in salary, but this, of course, is tangible only to the man himself. There is no necessity for him to change laboratories or office. This type of promotion is similar to that of a university faculty member.

I by no means wish to quarrel with the value of titles for the research positions. Not only do they provide a method for publicly recognizing and rewarding a man's contribution to the company, they also furnish a record of his progress if, for any reason, he changes employers. My criticism is rather with the tendency to identify these titles with administrative positions and imply similarities that do not exist. The pure research scientist cannot really be a member of management, since his first allegiance must be to science, rather than to company policy.

One final factor which can work against job satisfaction in the technical group stems from the time scale for basic research. In a laboratory combining fundamental research, applied research, and development groups, priority for laboratory services must go to the more urgent development projects. The experience of having to wait weeks for an analytical result which will determine the direction of further experiments can be very frustrating to the research scientist. Certainly the man cannot be blamed for consid-

ering his own work urgent although the particular results may not be of any immediate use to the company. If, in addition, he finds that management has little time to spend on his results and his plans, he may begin to doubt his own importance in the organization.

So far I have stressed the factors working against job satisfaction in the technical position. What can be done to overcome these? I would like to offer these suggestions.

(*1*) Recognize the unique role and needs of the men in the technical group; avoid comparison and competition with the administrative organization.

(*2*) Reward the research scientist according to his professional competence and contribution to the company, not on the basis of artificial alignments in organization charts.

(*3*) Provide equitable priorities for laboratory services.

(*4*) Provide, as much as possible public evidence of increasing status in line with titles. The most useful and valuable award here can be progressively greater freedom, more freedom to attend professional meetings, to publish papers, to choose research projects, even to obtain paid leaves of absence for study and research.

(*5*) Be willing to devote time and attention to the results of basic research and their possible utility. Make the scientist feel he is important in the company as well as in his professional field.

A senior scientist program is a company's investment in the future. Like all investments it is a gamble, but the likelihood of success can be increased by adopting policies aimed at attracting and keeping able scientists. With competition for these scientists from universities, government laboratories, and their own administrative organizations, industrial laboratories today will find it increasingly necessary to offer unique opportunities and rewards.

IMPROVING THE TECHNICAL COMPETENCE OF RESEARCH WORKERS

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In February 1960, the writer attended an IRI study group conference at which the subject of discussion was the means for improvement in technical competence. This paper is a presentation of some thoughts and experiences on that subject.

"Larry, that hydroxyl number that you asked about was 304. Here are the calculations and duplicate analyses." I ran through a quick calculation on the slip of paper that George handed me and was thrilled to find that it agreed very closely with the theoretical value for the compound in question. "George!, it checks! it's the monoglyceride." This answered specifically a question which we had asked ourselves some time ago and was the result of a definitive experiment to provide a yes or no answer. There had been some debate in the literature and this point would certainly make a good publication. This was one of our better days.

The next morning George came to see me again. "Larry, that value I gave you yesterday is off. I checked the normality of the reagent this morning and it seems to have changed since last time. The correct value is 356." There was no need to recalculate precisely to tell me that there was no possibilty that the compound could be the monoglyceride. We struggled with various

interpretations for several days but could come to no definite conclusion. I was still lucky, however, because the chemist had found the mistake promptly and let me know at once. How often has such an experience, or one much more serious, happened to you?

The importance of technical competence is readily recognized when one considers the increased cost of research and development, both total and per man-hour. The increasing necessity for high quality performance and the continued demand for well qualified persons make it imperative for management to make every effort to have the chosen work done in the best possible manner. It is well understood that the choice of problems is certainly one of the most important steps in conducting a research program, but that aspect is not considered here.

In organizing this discussion we can distinguish several topics, such as the persons with whom we are concerned, the factors characteristic of technical competence, methods to measure these factors, the recognition of the need for improvement, the motivation of people to make the effort to improve, the preparation of a program to increase this competence, its subsequent execution, the evaluation of the resulting performance, and the appropriate rewards. The success achieved can then be reviewed and the cycle repeated to continue the efforts to increase technical competence.

The persons with whom we are most concerned are professional laboratory workers at the bench level. We may include first line supervisors where technical competence is also of considerable importance and in some cases laboratory technicians. We intend to omit administrative persons and technicians following routine procedures. Cognizance should be taken also of ages and levels of responsibility and of performance that can be reasonably expected.

Among the factors which are characteristic of technical competence are operational skills, technical knowledge, application of both to specific cases, correlation and interpretation of data, and communication skill, both in receiving or learning and imparting

or informing. These factors are demonstrated in various stages of a research and development program which could typically consist of *(1)* initiation, *(2)* execution, *(3)* transfer, and *(4)* termination. Initiation includes recognition of the scientific and technological needs and the goals to be achieved and the conception of various possible solutions of these goals. Initiation also includes design and planning of experiments, which require familiarity with the information already known, selection of the most probably successful line of attack, of the variables to be controlled, and of materials and processes to be used. Estimates may be made of material and operating costs, by-products, hazards, and new equipment needed or modifications required of present equipment. The next step, execution, for a typical chemical project, would involve synthesis, isolation, characterization, and identification of products, calculation of yields, energy and material balances, rate studies and analyses of raw materials and products. Operational skills in laboratory techniques are important here in order to get pure products in high yields quickly. The next step would be transfer of the program to the stage that follows in the chain of operations from research to development to production to sales. When development studies are performed by a group different from that doing the research it is desirable for the technical competence of each to be matched, though, of course, not identical. The same is true, perhaps to a lesser extent, of the production and sales divisions. Effective communication between persons of very different backgrounds and interests is necessary. The final step, termination, includes the closing of the project, whether it be successful or not, and issuing the appropriate reports. This calls for organization and interpretation of data and communicative skills.

It is obviously necessary to have some methods to measure these factors comprising technical competence. It would be desirable to make these as objective as possible, but it is inevitable that a large amount of individual judgment cannot be escaped. The subjective factor can, however, be minimized by utilizing

the judgment of more than one person. Most organizations have personnel rating forms and procedures, and the factors of technical competence outlined above can be included. Evaluation should be on the basis of effectiveness in getting the proper work done, not merely in conformity to standard operating procedures. We should also remember that there are some absolute standards as well as group averages. It is all too easy to have a group whose average is unsatisfactorily low; persons who meet the average of a superior group should be recognized as very desirable and rewarded accordingly.

Improvement of technical competence is most efficient when the specific needs are adequately recognized by all concerned. Having identified the persons concerned, factors to be included, and the methods of measurement and evaluation, we may survey the organization and note the specific needs of each individual or of those research areas which may need a type of competence not well represented. Agreement on each specific need should be reached between the supervisors and the workers involved.

The improvement, involving change, requires a high degree of motivation of the people concerned. Of particular importance here is the clarification of the goals which are being set. It would be desirable to have specific goals for each individual as well as general goals to stimulate creative suggestions for further research. An important factor in motivation is to be sure that the assignments are properly made. An individual is rarely generally incompetent, and it is essential that interests and skills fit the job assigned. A high degree of technical competence in supervisors is a strong stimulus to the workers.

Motivation is generally achieved by combining the desires, ambitions, and professional objectives of the workers with the objectives of the activity sponsoring the research. There have been many discussions of motivation, and there are a number of standard well-known policies and procedures. It should be sufficient to say that the policies should be fair and the practice con-

sistent. This is complicated by the fact that both the effective motivating forces and the personal objectives of different individuals may vary considerably, and the factors which motivate one person may be quite different from those effective with another. The subject of motivation is closely connected with that of rewards, to be discussed later.

Competition itself is, of course, a strong motivating factor. This can be between associates within the company as well as between competitive companies. Competition is real and scarcely needs to be emphasized. The necessity to increase one's competence in order to maintain relative position is obvious to all. This applies both to individuals and to whole laboratories. Management must keep the normal competition existing between individuals within professional bonds and strive, rather, to foster cooperation between co-workers.

Jack and Ed had been assigned different phases of the same general problem. Both seemed to be converging on the same solution. They had frequently discussed their opinions on the principles involved and each had arrived at a partial solution. The patent lawyer, in an effort to determine if one or more inventions existed and if so, who might be the inventors, questioned them at some length and decided that there was only one invention and one inventor. Both of the chemists involved doubled their efforts to extend their respective ideas to determine the applicable limits and conditions for the reactions which they proposed. They also did a great deal of library work and discussed their ideas with other people who had had some experience in related fields. As a result in a relatively short time we had a far more complete picture of the chemistry involved than we had expected to get. Not only did we have a solution to the original problem, but we had several other possible applications as extensions of the basic idea. As a result, two or three other inventions were formulated with corresponding credit to both persons. Had it not been for the strong desire of these men to give a good account of themselves, not only would

we have had much narrower patent coverage, but relations between several persons would have been rather strained.

The selection of the means to increase the competence of technical personnel and the subsequent execution of this program are others of the important phases of the whole program. If the need has been recognized both with respect to the persons involved and the specific factors that need to be improved, the preparation of the appropriate program to meet these needs can be logically and efficiently developed. The programs may be carried out both away from the job and on the job. The first would involve such procedures as granting a leave to attend special courses or to complete work for a Ph.D. It may be better for persons to go away for short intervals of one or two weeks spaced a month or two apart than to be away for several months. Other means are evening or weekend courses and symposia or short courses of one to two weeks on special subjects.

With respect to on-the-job training, the initial assignment is extremely important and technical competence should be emphasized from the beginning. The new worker starting his first assignment keenly needs and deeply appreciates the personal attention of a mature and professionally minded supervisor. The assignment should require competence somewhat beyond that which the individual initially possesses. Orientation with respect to the operations and goals of the particular group and of other groups is highly desirable. Visits to or tours of duty with other groups for a week or two after a general introductory period are found effective. A variety of laboratory techniques may be acquired this way. Sources of information include company reports and publications, library journals, seminars, professional meetings, lectures, and courses by the staff, with assistance of specialists from other institutions. Consultants may also give help in specific technical areas. Continued coaching by senior associates or supervisors is quite effective, if organized well. An

increase in competence of one person or group will usually start a chain reaction and affect other workers with whom he comes in contact.

The program must be executed, and here the responsibility is very largely that of the immediate supervisor and the individual workers. If motivation has been strong and effective, the execution will need little attention by the supervisor, other than to see that the various aspects are suitably coordinated. Even though little of the supervisor's time may be needed, he should make clear his serious interest in the program and encourage its success.

As an example of a program to improve chemical laboratory technique we may refer to the "practicum" examination required of graduate students in some universities. The chemists may be assigned the preparation of a compound in certain purity and yield, to be completed in a limited time. They must consider possible methods of synthesis and select one appropriate for the purity, amount, time, and equipment involved, set up the necessary apparatus, purify, perhaps dry, the reagents, conduct the synthesis, then plan and execute the isolation, purification, characterization, identification, and analysis, perhaps by functional groups, of the product.

"Nothing succeeds like success." Many times we have seen a remarkable and highly favorable change occur in a young research worker as a result of having achieved a definite success in some phase of his research program. Many of the problems based upon insecurity, unfamiliarity, and the feeling of not yet having proved himself in the organization are quickly relieved when he has made a recognizable contribution. If the first problem to which a new man is assigned does not yield very satisfactory results either of a practical or of a theoretical nature, we have for some time endeavored to provide a second problem formulated in such a way as to be almost certain to provide clear success if not practically, then suitable for a publishable paper. Very often after a success of this sort, the more difficult problems are attacked by the chemist with renewed spirit and intensity and success leads to success.

The evaluation is necessary in order that the suitable rewards may be made. The results of increased competence should be revealed in the laboratory work itself, as this is the object of the whole effort. If adequate methods to measure the technical competence have been worked out before, the application of them to the evaluation of the success in applying the program should be fairly straightforward. If the evaluation does not proceed smoothly, one can suspect that the methods for measurement of competence were not well developed.

Rewards, in order to be effective, must be real and significant. They may be negative such as withholding raises or promotions, reprimands, or termination. Incompetent and ineffective persons have a very adverse effect on the morale and performance of their associates. The usual rewards are a substantial increase in salary, use of titles, offices, awards for patents or publications, stock options, increased vacation, bonuses, and the like. Among the especially desirable rewards is permission for an individual to set his own objectives which he can change both with respect to content and to timing. The recognition throughout the laboratory that certain individuals have this independence is apt to be a considerable stimulus to others to achieve this status for themselves. Also, an increased voice in management, particularly in regard to the individual's own work, is an effective stimulus. Another factor is the stimulation of intellectual curiosity and the sense of accomplishment through seeing tangible results occur from one's work. It is customary for research persons with some degree of independence to have the opportunity to do publishable work.

In conclusion we should point to a further aspect of this subject. Attainment of increased competence by those persons for whom a supervisor is responsible can be one of his greatest sources of satisfaction and that is in itself a great stimulus and motivating force. Its value lies not only in increased profit to the company and the effectiveness of the research organization, but also in the

effect on the lives of those persons. They will almost universally respond and express their gratitude and loyalty in service far beyond that which might normally be expected. Any supervisor who has had success of this sort has and will continue to have the thrill of seeing his people respond quickly and eagerly to those new problems that always arise in the pursuit of a planned program. That alone is enough to convince us of the value of all of these efforts to achieve greater competence in our daily tasks.

Appreciation is expressed to numerous friends, especially those attending the 1960 study group conferences of the Industrial Research Institute on this subject, and to my colleagues at the Armstrong Cork Company for helpful discussion.

A THEORY OF COMMUNICATIONS IN A RESEARCH LABORATORY*

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INTRODUCTION

At the IRI Fall Meeting in 1958 a report resulting from several study group sessions on the environment for creativity was presented.[1] In that presentation the problems of communication in a laboratory were glossed over with the excuse that there was not sufficient time and, in any case, there had been many writings on the subject. It was probably the stirring of an uneasy conscience that prompted the author to be persuaded much too easily to make this presentation. The following, which probably should be entitled "One Man's Opinion on Communications in a Research Laboratory," contains many sins of omission, or narrowness, and of oversimplification. At the same time it brings together some scattered ideas into what is—to the author at least—a rather satisfying picture.

Business management deals with a multiplicity of problems which can be arranged in a long continuum on the basis of dependence on probabilities and uncertainties. At one extreme can be placed the completely automated or mechanized production department. Here an attempt is made to program all activities very

* Paper presented at the Annual Spring Meeting of the Industrial Research Institute at Virginia Beach, Va., May 8–11, 1960.

precisely in advance and to control them from information in properly established feedback loops. This is the acme of "scientific" management. Uncertainties are kept to a minimum, and those that do exist are expected to be minor and easily handled. At the other extreme is the exploratory and basic research laboratory where uncertainties are very high indeed. Here the possibilities for precise control of productivity are nonexistent. Here we have to depend on the older, less scientific management skills of intuition and judgment.

Consider, for a moment, an old illustration as an extreme in the spectrum of probabilities—the case of a zoo full of monkeys who pound on typewriters for billions of years and who have at least a finite probability of expounding an Einstein theory. This gross exaggeration can hardly stand much comparison with a modern research laboratory, but it does serve to illustrate one of the basic premises of this discussion: Starting with such a tribe of monkeys the present-day research manager will immediately try to make changes which would improve the probability of obtaining a worthwhile output and of obtaining it sooner.

We have learned quite a few ways of raising these probabilities as they apply to a research laboratory. We have replaced the monkeys with intelligent beings—we call them research scientists and engineers. To be eligible for our environment, we have required them to come equipped with an extensive education in specialized fields of interest to our businesses, and we have continued to educate them after they have been acquired. We have required that they be screened by many processes and at many levels in order to assure ourselves that they are from the top layer of creative individuals. We pay them well, give them expensive equipment in great profusion, and house them in fancy chromium and glass laboratories. Finally, we immerse them in a continuing flood of information and watch the game run. We are convinced that, if we have been sufficiently clever in doing all these things, we will have influenced the probabilities to the extent that our efforts will earn much more money than we will have invested in

the process. Even so, we would like to have a still further improvement in the odds.

The purpose in introducing the subject in this way is, of course, to put as much emphasis as possible on the probabilistic nature of the research process in preparation for properly placing the role of communications as a major controlling factor for the probabilities involved.

None of us will question the critical importance of information flow or communications in the successful functioning of a research laboratory. However, we must continually ask ourselves what we can do to our information flow to improve the creative output of our laboratories. It is impossible to overestimate the complexity of this problem, and any attempt to elucidate it in detail in the short span of this presentation is foolhardy. However, an attempt will be made to look at some of the boundaries of the problem in the hope that it may be possible to circumscribe some promising areas in which to look for solutions.

Communications Systems

Let us first consider physical communications systems with which we are all familiar, such as the telephone, radio, or television. In quite general terms such physical communications systems consist of the following:

(*1*) A message source, which in the physical system may be a man, a computer, or a machine.
(*2*) An encoding device, analog or digital, which puts the message into a form that can be processed by the system.
(*3*) A transmitter which converts the encoded message into a signal and transmits or projects it toward a distant receiver.
(*4*) A medium which carries the transmitted message.
(*5*) A receiver which accepts the signal from the medium and translates it back to an encoded message.

(*6*) A decoding device which returns the message to a form that is a close copy of the original.
(*7*) A message destination which may be another man, or computer or machine.

It is probably not surprising that human communications can be considered as being accurately analogous to the physical systems. The brain originates the message and encodes it into language. The muscular system becomes the transmitter which converts the encoded message into sound waves or marks on paper to be transmitted to the receiver (ears or eyes) to be converted back into language and then decoded into the message in the brain. The cynic will say that the human communications channel is not very good compared with its engineering counterpart—how seldom is the message in the receiving brain *identical* with that in the sender's? Nevertheless, the two systems are analogous, and most of the concepts used by communications engineers can be applied to the human system.

The most important characteristic of any communication channel is its capacity, that is, the rate at which information can be passed through it. The basic unit quantity of information is the bit, and rates are expressed as bits per second. In practice, any communication channel operates at or below its maximum capacity. The actual operating rate is dependent on the amounts of interfering noise and distortions or inaccuracies of operation in the system.

Measurements that have been made on the maximum channel capacity of human beings have given surprisingly small numbers—usually a few tens of bits per second. The actual number is not important for our purpose. What is important is the *existence* of a definite limit and the fact that the limit is very small relative to the total amount of information in existence. In other words, it is easily possible to attempt to pass enough information through the human communication channel to exceed its capacity.

Miller[2] and a group at the University of Michigan have been

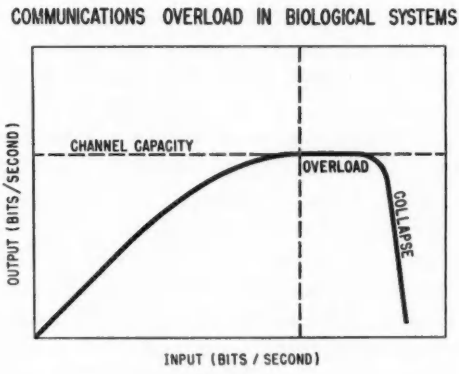

Figure 1.

making a study of what happens when a biological communications channel is overloaded. The results of this study are illustrated qualitatively in Figure 1, where the input information rate is plotted against the output rate. For low input rates, that is, well below the channel capacity, the input and output rates are approximately equal. As may be expected, as the input rate increases the output rate approaches the channel capacity asymptotically. Practically, this means that there is an increasing number of errors and omissions in the transmitted information as the input approaches and exceeds the channel capacity. When the channel capacity is greatly exceeded, the system collapses as a communication channel and nothing is transmitted.

Since evidence of channel collapse is not too common, we can reconcile the channel limitations of the individual human and the excessive amount of information available to him by assuming he exercises intelligent control over the *quantity* of information he processes.

Let us now take the next step and consider man as part of a system—society, if you like, or even part of a research laboratory. Here, too, there is an engineering analogy. Each man looks something like the central switching station of a communications

system. He can establish communications channels with many other such stations and can transmit to or receive messages from any of them. He can route messages through himself to others or can store them for indefinite periods of time for future routing. On looking a little closer you see that he is a rather special type of central station. The engineer would say that he operates on a time-sharing basis. For our purpose, this means that at any one instant he is communicating on only one channel. While he may establish a number of channels, he will control the quantity of information flowing in each of them such that the total rate does not exceed his channel capacity. The problems this generates in an organization are easily sensed from Figure 2, which is an exact mathematical plot of the possible communications channels that can exist in groups consisting of the numbers of people indicated as the abscissa. Two curves are shown. The lower curve gives the relationship between the number of possible pairs of communications channels and the group size. The upper curve is the number

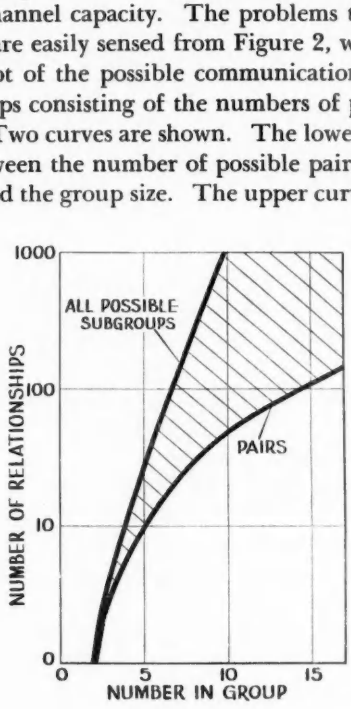

Figure 2.

of all possible subgroups (pairs, triplets, groups of four, etc.) within the total group. These curves can be considered as measures of the total possible information flow in groups of the sizes indicated. There is no need of going into the quantitative relationships between these curves and the amount of information that must flow from the group to any one individual in the group to enable him to carry out his specific purpose. The important point is that the curves rise extremely rapidly for groups numbering more than five or six individuals. (Incidentally, these curves give rather good support to the organization expert's contention that a manager's span of control should be limited to only six or seven functions.)

Since these numbers are very small compared to the sizes of the groups that may be involved in an individual's total communications environment, it becomes clear that communications overload is a normal state and that control of the quantity of information in the individual's channel is an ever-present factor in his behavior.

Until now only the control of the quantity of information has been discussed. In both the establishment of communications channels and in the processing of information in the channels, control of the quantity is exercised by a process of selection. Obviously, the *quality* of the information flowing in an individual's communications channel will also be determined by this process of selection and therefore by the intelligence, experience, and skill which he applies. In the case of an individual in a creative pursuit, the determination of quality will include a substantial probability factor, but will depend on the application of the same individual characteristics.

The Communications Environment in the Laboratory

Let us now examine more specifically the communications environment in which the individual in the research laboratory lives. An attempt has been made to depict this diagrammatically

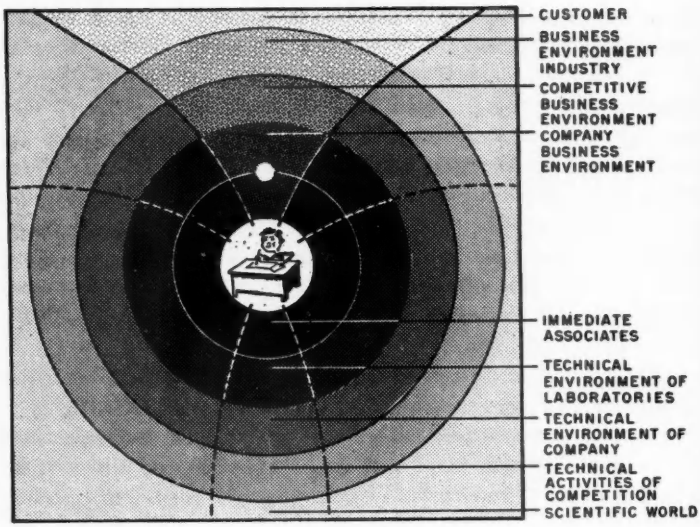

Figure 3.

in Figure 3. For the moment we shall assume that the central figure is a "bench worker" in a laboratory. The individual under consideration has been placed at the center of his communications environment since that is how he sees it and that is how he reacts to it. Since much of a research manager's success is dependent on the "communications judgment" of each of the individuals in his organization, each of whom should be considered at the center of his own environment, it is important that he understand the communications environment from the worker's point of view. A rather sharp distinction has been made between the technical and business portions of this environment, largely on the assumption that the technical worker views the situation in this light. Each of the concentric circular strips represents a major group of other individuals who can establish communications channels which involve the central figure and in which information can flow both

ways. In the real situation, it is clear that each group merges with the next with no sharp boundaries as drawn.

A more complete picture would have filled the circular areas with dots to represent people and a set of lines joining pairs of dots to represent established channels. One can easily visualize that the lines representing the channels would appear as a complexly interwoven cobweb with a general converging to the central point imposed by the way we have drawn the diagram.

If we now consider the loading of the communications channels in this system, we find that the connections between the central figure and the relatively small number of immediate associates would be most heavily loaded. Toward the periphery, where the number of possible connections with the central figure (either direct or indirect) would increase rapidly, the loading of the channels must decrease.

The white dot immediately above the central figure was put in to suggest the immediate supervisor. He is one of the central figure's immediate associates and probably his most concentrated source of business information.

Redrawing this figure to represent the situation for successively higher levels of supervision requires very few changes. The dots representing the individuals in the communications environment, visualized above as forming the basis for the concentric areas, would be essentially the same dots rearranged about the different central figure. There would, of course, be some additions and deletions of dots representing specific individuals. The most evident change would be an increase in the area representing business type communications relative to that of technical communications, to indicate the change in emphasis as we go to higher levels of supervision.

Let us return now to the central figure, the technical worker from whom we expect to obtain creative ideas. From Figure 3 it is obvious that the information flow inward to the central figure can exceed by a very large factor the capacity of his single channel system. He is not going to "crack up," few of us do, because

subconsciously and consciously, he is going to exercise that control which will keep the information flow at least below the overload point and preferably below the inefficient range. He has two parameters with which to work—the selection of the channels (very few from very many) and the acceptance of the content. Selecting the channels controls the quantity and to some extent the content. The evaluation of the quality of the content provides the feedback for the control of future channel selection. The situation is quite similar in the outward flow of information. Here too, the possible number of channels and the possible content far exceed the central figure's transmission channel capacity. Again, he controls the information flow by selection of the channel and its content. Similar feedback loops are present in this process. Still other interactions exist between the inward and outward flow of information.

Creativity and Communications

If we can agree that a necessary but not sufficient condition for the striking of a creative spark is that the necessary information, or deductions therefrom, come together in time and in a single mind, and that such coincidence cannot be programmed, we can now draw certain conclusions. For instance, it becomes apparent that the probabilistic character of the creative process and therefore of research is highly dependent on the uncertainties imposed on the communication process by the low channel capacity of humans and therefore by the necessity of making selections without *a priori* knowledge of how to make them. Research managers interested in raising the creativity of their laboratories must search for means of increasing the probability of coincidence of the necessary information, also without *a priori* knowledge of the content of the coincidence. Finally, there is the very important role played by the individual in controlling and processing the information flow. He makes the decisions as to the acceptance of the content of the information and as to how he will process it.

He has a strong influence in the selection of incoming channels and complete control of the selection of outgoing channels. All of these decisions will be made on the basis of *maximizing his personal benefits,* whatever he thinks them to be.

Thus we have constructed a model of the communications environment of a research scientist in which he is at the center of that environment, is forced to maintain his rate of information flow below a small maximum by selection from a large quantity, and in which he must control his selection in a way which will increase his probability of accomplishing something creative. In taking these actions he must conform to two other boundary conditions. First, he cannot specify in advance the information necessary for the striking of a creative spark. Secondly, his control will be exercised in a way which benefits him personally because of its value to his work and to the company.

Once the boundary conditions of this model are recognized, some of the actions, which the research manager can or cannot take to help the research scientist, begin to suggest themselves. For instance, he cannot attempt to program (that is, specify in detail) more than an extremely small fraction of the channels of communication or their content. The total system is too complex; the research manager has no foresight to know toward what he is programming and the final judgment resides with the individual worker.

It also has become clear that the research manager cannot increase the probability of a creativity-inducing coincidence of information by simply adding the "right" information to the total flow in such large quantities that the probabilities must be weighted in his favor. His lack of foresight again leaves him with no basis of selection.

On the positive side, management must communicate a certain minimum amount of information to the individual on his technical staff:

(*a*) The objectives and technical needs of the company.

(*b*) The true value of the rewards (professional recognition, freedom of selection of technical approach, salary, etc.[1])

that management is offering for the attainment of those objectives and the satisfaction of the technical needs.

It must be remembered that this information must reach the staff member through the competition of the total information flow. The fact that the channel is connected to management may give it a slightly higher priority, but the content still has to contend with the special filters built into the receiver for that channel. "Getting through" to the individual requires special attention. Barnard[3] has stated the requirements extremely well; in brief, he says that, to carry authority, a communication must:

(*1*) Be understood by the recipient.
(*2*) Be compatible with the recipient's understanding of the organization's objectives.
(*3*) Be compatible with the recipient's personal interest.
(*4*) Be within the recipient's mental and physical ability to take action.

Having communicated the objectives and needs to the technical man, the research manager is now dependent on him for further progress and is at the mercy of the probabilities inherent in the system.

The remaining suggestions are both specific and general and concern means whereby the research manager can cooperate with the research scientist to raise the probability of creative events and therefore, the productivity of his laboratory.

The Telephone Directory Approach

As implied by its name, this very specific approach involves the distribution of a directory compiled on the basis of "who knows what" for the organization. It is a listing of all the fields of competence in the organization along with the name, location, and telephone number of the individuals having each specific competence. The fields of competence are subdivided into sufficiently

small segments to ensure the inclusion of the name of every professional worker at least once. The directory is very thoroughly cross-indexed. Furthermore, there is a correlation between the breadth of each subject heading and the breadth of responsibility of the individual named with it.

By means of such a directory, it is possible to increase considerably the efficiency with which an individual can obtain information in a field he believes will be of value. In terms of the communications model, it is a means of improving the process of establishing communications channels. It does so as a tool to aid the individual's judgment without limiting it. While the directory has been described as being internal to the organization, it is clear that it will also provide indirect access to relevant outside contacts.

The Advertising Approach

The research worker is continually generating new knowledge. Much of it is minor detail, but occasionally it may be much more significant. It has always been recognized that new knowledge should be communicated to other interested scientists in the expectation that, coupled with the information in other minds, there is an increased probability of making an important discovery or invention. As a result, it has become traditional for scientists (perhaps with an eye also on their personal prestige) to write and publish technical papers. This practice has carried over into industrial laboratories in the form of comprehensive technical reports which are distributed to the executives of the organization, to the libraries and to just a few individuals who, in the opinion of the author of the report, may be able to use the information. There are several obvious defects in this procedure. The full report is contributing to the overloading of the communications channel, particularly of the executives and others who are not interested in the full contents. While it becomes available to everyone through the library, evidence of its existence is usually buried in a long periodic list of new acquisitions. Most important,

however, is the fact that no one, including the author of a report, can predict where the report should be sent to derive the maximum benefit to the organization.

Why not use an advertising approach? In other words, after the report is completed, send full copies only to the library and the few other locations which must have it for legal, patent, or record-keeping reasons. Then, to a much broader distribution list than would be possible for the full report, send an "advertisement" consisting only of a very brief statement to the effect that: John Doe, Room ABC in the XYZ department has done the following work with the following results. Complete story in Report Number LMN.

The busy executive can read this and pass it on faster than he can find the title page in the complete report. The recipients among the technical people will be able to do the same. This technique increases the probability of a useful result, in that larger groups of individuals who would not have received or would not have read the full report are made aware of its existence. In terms of the communications model, the technique provides an increase in efficiency by indicating which channel of communication should be established only when it is profitable to do so.

Education

This is a more general approach by which research management can improve the probability of communications effectiveness. It is suggested that a course for technical personnel be given in which communications theory and its implications in human communications are developed rather completely. Research management is perhaps overlooking the contributions which might be made to the solution of this problem by the highly creative members of their technical staff. The firm technical foundation of communications theory and the development of the human communications problem in terms of probabilities should provide a more than adequate challenge. Since the stimulation of some

serious thought on problems of communications is desired, such education should avoid the presentation of the standard clichés. These may be perfectly valid statements, but being completely predigested, require no thought and usually get none.

Communicating Versus Doing

The communications model developed in this discussion illuminates the insidious danger inherent in the imbalance between the limited capacity of the human communications channel and the infinite source of information in our environment. It becomes very easy to fall into the trap of communicating to the almost complete exclusion of doing. In spite of this there is a preponderance of propaganda devoted to emphasizing the importance of communication. It seems appropriate to recommend some countermeasures which will place emphasis on the necessity of a proper balance between communicating and doing. Some studies could be initiated to consider the optimum division of an individual's time between doing and communicating. Our best scientists and managers have obviously solved this problem for themselves. This is not always true for our more nearly average technical people. Perhaps there is a large store of latent productivity that can be brought into use by giving the average technical man a target for the proportion of his time he should spend communicating versus doing.

One approach would be to make studies in depth of the communicating and doing habits of workers who are recognized as being successful in their respective fields. The study would search for patterns which might lead to rough bench marks on the division of time. Then some bold research manager may experiment with applying these bench marks, probably through the medium of education, to his average workers. Undoubtedly, doing no more than establishing the concept of an optimum time division would make a worthwhile gain.

Conclusion

The foregoing has been a preliminary attempt to base the probabilistic nature of the research process on the disparity between the limited capacity of human communication channels and a communication environment in which there is an unlimited amount of information. The discussion leads to the suggestion of some different approaches to increasing the probability of obtaining a profitable output from a laboratory.

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BOOK REVIEW

Handbook of Industrial Research Management. Carl Heyel, editor. xvii + 513 pages. Reinhold Publishing Corp., 430 Park Ave., New York 22, N. Y. 1959. $12.00.

In 1948, the IRI sponsored *Research in Industry*, edited by C. C. Furnas. In its 29 chapters and 574 pages written by 36 research executives of 27 leading corporations and the National Research Council, it represented the first broad collaborative attempt to record between two covers "the principles and experiences which have repeatedly proved to be applicable and valuable" in research management. But, as stated in its preface, "the organization and administration of industrial research constitute an art that can never be encompassed by a book of rules."

Twelve years later, the subject of this review is published, dedicated in its preface to systematizing "the management function which has proved least amenable to confident long-range allocations and effective operating controls." In 17 chapters and 513 pages, it presents the principles and experiences of 33 other contributors on 20 of the 28 subjects treated in the earlier book, plus three new topics. These are: organization for information research, use of electronic computers in research, and government contracts. Fourteen of the contributors represent 8 IRI members; 17 are management consultants, and 2 are with a professional association and a university respectively.

Not only does this new book give the views of a different group of experienced men, but it reflects progress in elaboration and refinement of management techniques which have been made since 1948. Recognition of management objectives, bases for evaluation, project administration, budgeting, and personnel recruitment, training and compensation, are examples of research management problems where progress is reported.

When the IRI book was published, it did two things: (*1*) it identified what research directors considered to be their principal objectives, and (*2*) it presented a set of statements of principles, experiences and opinions with re-

spect thereto. Without being dogmatic, it established a tangible standard or datum with which others could agree or disagree. It stimulated a flow of papers which have greatly extended our understanding, even where more often than not, the subjects remain controversial. In that sense, the IRI book was written primarily for professional research directors and secondarily for other corporate officers, though it has been of great benefit to both.

The *Handbook of Industrial Research Management* provides primarily corporate officers and key personnel other than those in the R&D department with a better understanding of the management problems and functions in research. The contents are conveniently arranged for ready reference, and can provide readers with a common language to facilitate communications and team effort. Written by professionals in big business, most of what is said is familiar to other professionals in large companies, if not necessarily taken as gospel.

The research manager in the smaller organization will find much in this book that is helpful, particularly if he has not had the time to follow the literature closely. However, it is written from the viewpoint of large corporate research, where the organizational and administrative machinery is more elaborate and ponderous. Many of the problems dealt with are vestigial in the small research department.

It is always difficult to criticize an earnest effort to contribute to a field where there has been and is so much striving for better understanding. But there is no formula for success in industrial research management nor in playing the stock market, or we should all be millionaires. Each successful corporation has worked out its own research system. There are various alternative solutions to most research management problems; there are others for which no satisfactory solution has been reported. The method that will prove best for one company is a function of many variables which can be evaluated only by experience, judgment, and skill in human relations. Designation of this volume as a "handbook" implies just the opposite of these ideas, especially to the corporate executive who has known all along that mass creativity could be organized and made "amenable to confident long-range allocations."

Furthermore, one would expect to find in a handbook of industrial research management adequate exposition of such important subjects as the transfer of research products to manufacturing; location, design, and construction of a modern research laboratory; instruments, supporting services, facilities, and other tools of research; having research done abroad; operations research; and aids available to executives concerned with research management. Other pertinent subjects not treated include white collar unions, personnel audits, project team approach, small business research, administrative

and technical ladders, and human relations. Relations with the public, government, education, and "other industries" were considered important enough to deserve three chapters in the 1948 book, yet despite their greater importance today, are not discussed. Perhaps the most conspicuous omission is any detailed discussion of development functions or of creativity techniques.

Instances of duplication, inherent to group authorship, are numerous. Chapter 12, for example, is repetitive of much in Chapter 11; quality control, a questionable topic for this book, is discussed in Chapter 9 without reference to earlier treatment in Chapter 3.

In summary, this book gives added support to the opinion that industrial research management has become too big a subject for one volume. Most of the major problems today, such as development, or personnel training, selection, and compensation, deserve a book apiece. Perhaps the book needed most, but not yet written, is one which might be entitled "Principles of Industrial Research and Development Management: A Guide for Nontechnical Corporate Officers and Directors." A retired president or chairman who had formerly been R&D director might make it both convincing and readable.

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INDEX, VOLUME III, 1960

Award for scientific and administrative accomplishment, job status as, 227

Basic research, industrial responsibility, 69

Bienfait, H.: Management policy of the Philips research laboratory, 201

Bralley, J. A.: Proceedings of the Industrial Research Institute study group meetings. Number 1. The environment for creativity, 97, 175

—: Proceedings of Industrial Research Institute study group meetings. Number 2. Job status as an award for scientific and administrative accomplishment, 227

Communications, 77
  theory, in research laboratory, 255

Creativity, environment for, 97, 175
  in research organizations, 217
  sustaining against organizational pressures, 49

Dunlap, L. H.: Improving the technical competence of research workers, 245

Effects of international product competition on United States research, 157

Freeman, R. J.: The basic resources of research, 13

Gershinowitz, H.: Sustaining creativity against organizational pressures, 49

Healey, F. H.: Job status for the research scientist, 239

Hillier, J.: Theory of communications in a research laboratory, 255

Howe, J. O.: see Marschner, R. F.

Industrial research, evaluation of capabilities, 127
  introduction of new graduates to, 39

Industrial Research Institute, study group meeting proceedings, 97, 175, 227
  study group programs, 93

International product competition, effect on U.S. research, 157

Investment analyst, evaluation of industrial research capabilities, 127

Job status, as award for accomplishment, 227
  for research scientist, 239

Kaulakis, A. F.: The bottleneck in effective personnel appraisal: identifying what is limiting and why, 5

Kipp, E. M.: Introduction of the newly graduated scientist to industrial research, 39

Kistiakowsky, G. B.: Basic research: an industrial responsibility, 69

Marschner, R. F., and Howe, J. O.: Better written reports, 147

Management policy, Philips research laboratory, 201

McLean, I. W., Jr.: see Stimpert, F. D.

Middle management, research and development, 85

O'Shaugnessy, M. T.: Middle management of research and development, 85

Pacifico, C.: Communications—the bridge across the chasm, 77

Personnel appraisal, 5

Philips research laboratory, management policy, 201

Poliomyelitis vaccine, development, 27
Product competition, effect on U.S. research, 157
Reich, I.: Creativity in research organizations, 217
Reports, written, 157
Research and development, middle management, 85
Research scientist, improving technical competence, 245
job status for, 239
motivating, 57
Resources of research, 13
Roehl, O. C.: The investment analyst's evaluation of industrial research capabilities, 127
Scientists, newly graduated, introduction to industrial research, 39
Secrist, H. A.: Motivating the industrial research scientist, 57
Stimpert, F. D., McLean, I. W., Jr., and Wilner, B. I.: Poliomyelitis vaccine: a story of its development, 27
Technical competence of research workers, improvement, 245
United States research, and international product competition, 157
Vaughn, T. H.: The research study group program of the Industrial Research Institute, 93
Wilner, B. I.: see Stimpert, F. D.

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Sworn to and subscribed before me this 29th day of September, 1960.

[Seal]

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(My commission expires March 30, 1961)